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November 1978

A Method for Evaluating Advanced Systems and Concepts for Ground Combat

E. Paxson, M. Weiner

A Report prepared for

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Rand
SANTA MONICA, CA. 90406

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This report Presents a method for illuminating the interrelationships between a proposed advanced ground combat system's technological characteristics and its tactical employment. The method uses a three-dimensional "terrain table," a computer program for determining whether and for how long a line of sight exists between a sensor and a target, and a series of analytic modules developed for a hand calculator to determine the outcomes of engagements. To illustrate the use of the method, evaluations were carried out involving advanced direct-fire and indirect fire systems. The results of such evaluations can highlight issues of system design and performance and point the way toward useful field tests, experiments, and simulations of advanced systems. The method is most valuable if used early in a system's conceptualization phase. (See also R-2376, R-2377.) 34 pp. (WH)

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PREFACE

This is one of a series of reports that describe a method for studying advanced employment concepts for ground force operations. The study was sponsored by the Tactical Technology Office of the Defense Advanced Research Projects Agency (ARPA). The objective was to develop new concepts for the employment of ground combat systems that incorporate advanced technology, and to define and evaluate weapon systems for implementing these concepts. This series of publications does not present the specific concepts, advanced weapon systems, and overall results of the evaluations, although some of the advanced systems and results are described to illustrate the evaluation methodology.

This report describes the overall study approach, focusing on the method for evaluating advanced combat systems. The method uses a three-dimensional terrain board, together with computer and analytic programs, for conducting a minute-by-minute evaluation of a combat situation involving advanced ground combat systems.

A companion Rand report, *The Terrain Intervisibility and Movement Evaluation Routine (TIMER) Model*, R-2376-ARPA, presents a detailed description of the use and the computer programs of the intervisibility model, which is a part of the evaluation methodology.

A third volume, *Interactions Between Tactics and Technology in Ground Warfare*, R-2377-ARPA, presents some implications for combat forces, based on the specific evaluations conducted in the course of this study.

[redacted]

SUMMARY

The detailed evaluation of proposals for improved ground-combat systems or concepts can assist defense planners and system designers in understanding the systems' capabilities and limitations before major funding commitments are made. If the proposed systems and concepts do not differ markedly from current ones, standard evaluation techniques such as wargaming or systems analysis are appropriate.

Special methods are likely to be necessary, however, for advanced concepts and systems that may dictate innovations in how a unit or force is organized, how it will operate, and the tactics it will employ. This report describes one such method. It can be used to illuminate the interrelationships between a system's technological characteristics and its tactical employment. It involves the following steps:

1. Outline the operational concept.
2. Establish the technical and operational characteristics of the system or systems.
3. Determine the organization, tactics, and communications of a force or combat unit that will be equipped with the systems.
4. Develop a hypothetical combat situation for system testing.
5. Carry out detailed "play" of the situation.
6. Analyze the quantitative and qualitative data from the play in order to:
7. Identify tactical-technological issues and determine trade-offs that affect the technical performance and specifications of the advanced systems.

The method described here uses a three-dimensional "terrain table," a computer program, and a series of analytic modules developed for a hand calculator. With these tools, a detailed minute-by-minute play is conducted. This permits innovative decisions to be introduced, friendly and enemy actions to be examined in detail, and tactical-technological interactions of the systems to be clearly understood.

The results can highlight issues of system design and performance and point the way toward useful field tests, experiments, or simulations that can help answer critical questions or reduce uncertainties in the further development of the advanced systems.

The evaluation method is most valuable if used early in the conceptualization phase of a system. Although the results will always be influenced by the geographic area chosen for the exercise, the tactical scenario, the tactical decisions of the participants, and other subjective components of play, they can provide useful insights into the capabilities and limitations of advanced systems and concepts. Expert judgment can adjust for the effects of these factors, which are unlikely to alter the major lessons to be drawn from the analysis.

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CONTENTS

I. INTRODUCTION

Defense planners must constantly consider proposals for new concepts and systems for military operations. Many are proposals for enhancing the firepower, mobility, command-control, or other aspects of the ground forces that face the growing Soviet threat in Europe. The Advanced Employment Concepts study was initiated to develop a method for evaluating concepts that incorporate advanced technologies and are suggested as initiatives for pursuit by ARPA's Tactical Technology Office. This report describes that method and illustrates how it was used for evaluating some advanced ground combat systems that were pitted against armored targets on a three-dimensional terrain board.

One of the concepts of interest was Distributed Area Defense (DAD), under which small units were distributed through an area near the border between the Federal Republic of Germany and the German Democratic Republic. These units were able to concentrate firepower on enemy units moving into the area. Two types of weapon systems employing advanced technology for the precision delivery of munitions were considered and assessed for this concept. The overall approach is shown schematically in Fig. 1.

One of the main tasks was to evaluate the operational utility of the advanced systems. The desired method for this evaluation called for the following characteristics:

- Innovational concepts could be introduced;
- Ground combat systems could be evaluated that incorporate advanced technology characteristics very different from current operational systems;
- The tactical situation could be represented in detail; and
- Considerable flexibility for the introduction of novel tactics could be incorporated.

A review of existing combat models concluded that none were suitable because they would require extensive modifications; hence the method described in this report was developed. It uses a three-dimensional model of a portion of the terrain along the West German-East German border (a terrain board); a computer model for some aspects of the analysis; and a series of analytic modules or programs for a hand calculator. The terrain board made it possible to represent tactical situations in great detail.

Fine-grain representation of the tactical situation is considered necessary for exploring the relationships between the operational characteristics and tactical use of ground combat systems that incorporate advanced technology—in short, the interaction between tactics and technology. This subject has often been neglected in the design of advanced ground combat systems; technical characteristics usually command most of the attention. In some cases, a system's utility is evaluated only by its performance in a benign environment against a single, highly visible enemy target whose location is known—a very favorable "one-on-one" situation. In most cases, little or no thought is given to the organizational structure to operate the system, the tactics for employing it, and its interrelationship with other combat

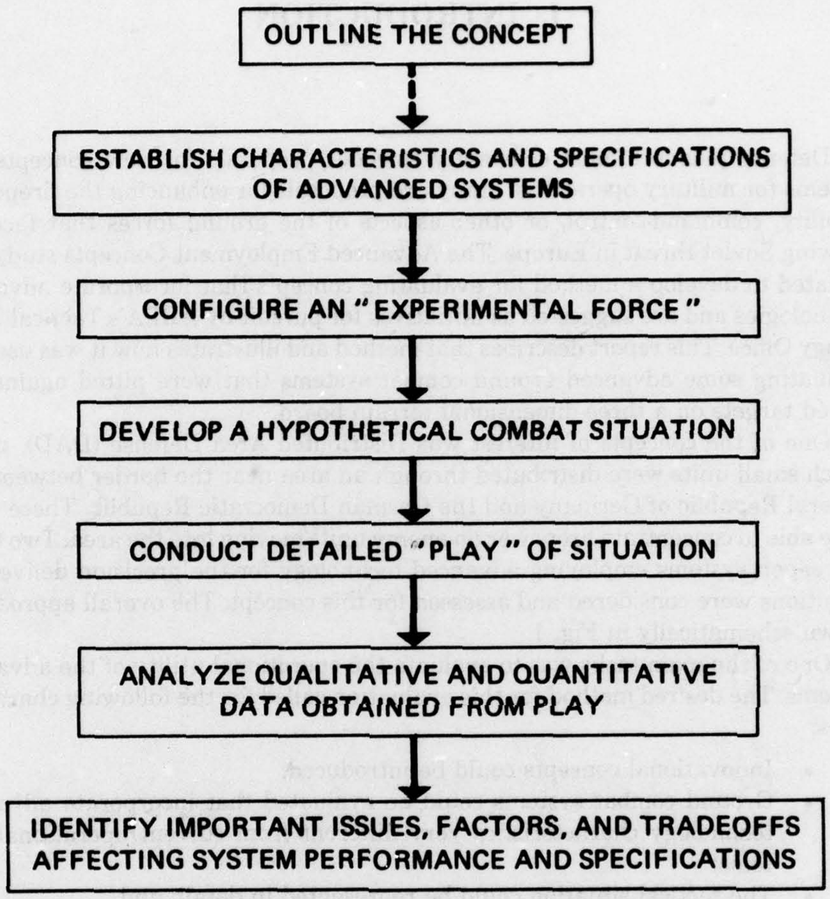


Fig. 1—Basic methodological approach of Advanced Employment Concepts study

systems in a combined-arms force. Under these circumstances, it is not surprising that estimates of the system's capability are often very high.

The Advanced Employment Concept study sought to overcome some of these artificialities through a broad evaluation that would reveal the system's capabilities and limitations before further development was undertaken. This required consideration of the neglected issues just mentioned, as well as a detailed look at the other half of the picture: how technical characteristics influence tactics. A list of questions was drawn up to pinpoint those interactions. Table 1 presents the most important ones.

Table 1

QUESTIONS ON TACTICS AND TECHNOLOGY

- Who sees whom at what distance for how long?
- How long does it take to bring fire to bear?
- How is fire allocated?
- How frequently are what weapons used against what targets and at what ranges?
- When, where, and why do units move?
- How do units coordinate with each other?
- What communications take place and when?
- How and when are units resupplied?
- How do systems complement each other?
- How vulnerable are these activities to enemy action?

To answer these questions using the evaluation method, the hypothetical combat situation needed to have four virtues:

1. It should be extensive enough in time and space so that a variety of engagements would take place: in the open, in woods, around urban areas, and so on.
2. It should provide a large number of "many-on-many" engagements.
3. It should be comprehensive enough so that the synergistic effects of the different combat systems in the force could be examined.
4. It should be flexible enough to allow for an array of enemy counteractions.

The method has been employed in two evaluations involving the DAD concept. The first evaluation, which was used as a test case, involved a force equipped with two systems: a direct-fire system consisting of a man-portable laser beam-rider missile, and an indirect-fire system employing a "guided mortar" that acquired targets from a sensor platform elevated on a tethered rotor.

Based in part on the results of this test exercise, the Systems Planning Corporation, under an ARPA contract, developed an indirect-fire system employing a sensor platform mounted on a telescoping pole and carried by an armored vehicle that also had a rack for launching beam-rider missiles. Figure 2 shows this vehicle, which was nicknamed "TALLBOY." The second evaluation involved this system.

This report does not include the major findings of these two evaluations, but it uses some of their data and results to illustrate various aspects of the general methodology.

The following sections of this report describe the steps in the overall evaluation approach shown in Fig. 1. The method appears to be particularly appropriate for use with advanced systems that are in the conceptual stage and for which organizational, tactical, and technological issues are to be considered. It may be less advantageous when an advanced system has already been developed and is to be incorporated into an existing organizational structure, when the tactical use of the system is well understood, or when tactical-technological interactions are not a major factor. Under these circumstances, existing combat models may be adequate for system evaluation.

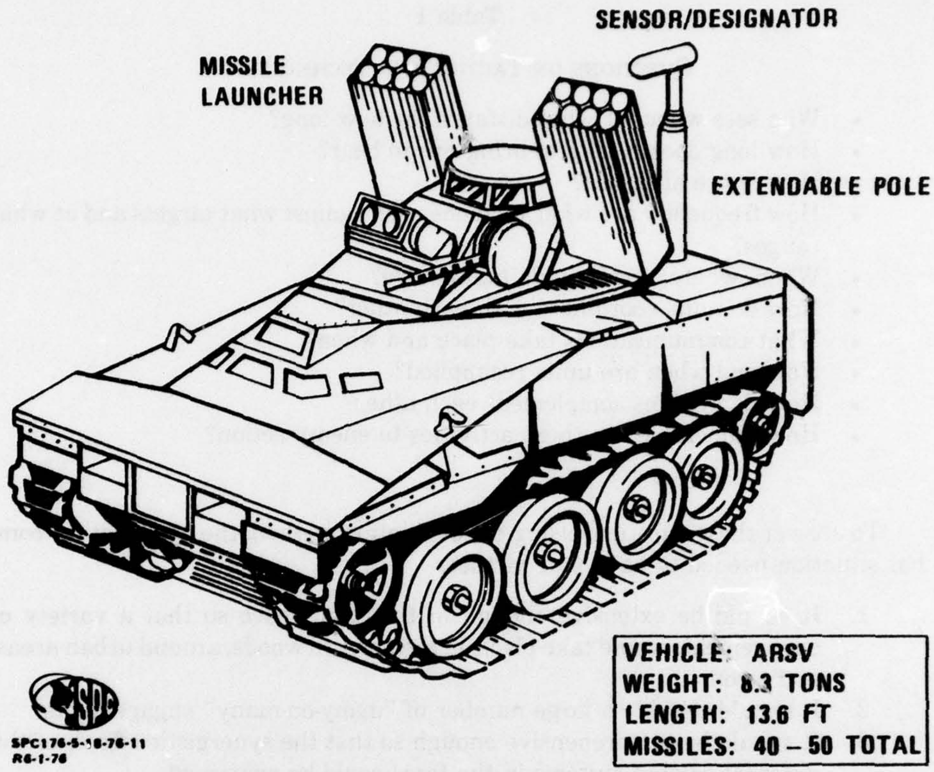


Fig. 2—Tracked indirect-fire target acquisition/engagement system

II. ESTABLISHING SYSTEM CHARACTERISTICS AND SPECIFICATIONS

Advanced combat weapons or systems originate in many ways. Sometimes a new principle or effect, such as nuclear fission, offers the promise of military applications. In other cases, known technical capabilities can be combined into a new system. And in still other cases, the pressure of a military requirement is the driving force behind technological advances. In this last case, considerable conceptualization or analysis may have already taken place to establish the requirements for the system.

In cases typical of ARPA research, the possibility of an advanced system, often one for which the technological aspects represent a high risk, is explored on the basis of the contribution it will make to U.S. defense capabilities, but many aspects of introducing the system into the combat forces are not treated in detail until there is evidence that the system is technologically feasible. The evaluation method described in this report is most useful in this type of situation, since it can shed light on the interrelationship between the tactical employment of the system and its technological capabilities.

In these cases, while the system is still in the conceptualization phase, or when its technological feasibility is certain, many of its aspects can be identified clearly enough to establish at least its gross system characteristics and specifications related to the operational employment. These characteristics and specifications represent the initial input to the evaluation.

As an illustration, the TALLBOY system in Fig. 2 may be considered typical. The lightly armed TALLBOY was conceived as a self-contained indirect-fire system, performing its own target area search, target acquisition, target designation, launch of weapons, and guidance to target.

TALLBOY has an extendable pole, made of ⅛-inch aluminum, that can be extended to 30 meters in 15 seconds. The sensor portion of the head is a Forward Looking Infrared (FLIR) (8 to 11.5 microns) with a 10 to 15 degree search-and-acquisition field of view (FOV) and a 2 to 4 degree FOV for identification and tracking. Its laser range-finder/designator is a 1.06 micron Nd/YAG with a beam divergence of 0.2 milliradians and a duty cycle of 60 seconds, repeated after 30 seconds of cool-down.

TALLBOY has two external ready racks, each containing 10 missiles, fixed in elevation at 60 to 70 degrees and slaved in azimuth to the sensor. From 20 to 30 additional missiles can be carried in hull storage. The two-stage missile has an all-up weight of 20 to 25 pounds. The missiles are soft-launched by a pneumatic or spring ejection mechanism at 80 to 120 f.p.s. and have a maximum range of 5000 meters. The missile employs semiactive laser guidance and carries a 3 to 4 pound warhead.

The sequence of events for operation of the TALLBOY system is:

1. Target search and acquisition;
2. Soft launch of missiles;
3. Laser designator on;

4. Missile initiates search;
5. Target acquisition by missile, fins separated, boost-sustain motor ignited;
6. High-velocity flight to target.

Given the technical characteristics of the system and the planned operational sequence, the "planning factors" to be used in the evaluation have to be developed. These include factors such as:

- Time to determine that observed target is an appropriate target;
- Response time to fire missile;
- Time of flight of missile for range to target;
- Rate of fire of missiles;
- Hit probability of missile;
- Kill probability of missile for different target types;
- Time for vehicle to displace to new position under various movement conditions (roads, trails, cross-country);
- Time to reload missile rack from internal storage.

Other planning factors, such as firing doctrine when several TALLBOYs operate in the same area, time to replace sensor pole if damaged, and the like, will also have to be established for an evaluation. Since some of these factors will vary depending on the engagement situation, the initial planning factor values are considered only as guidelines, with variations to be introduced as required.

The initial effort in the evaluation method thus involves establishing the relevant technical characteristics of the advanced system, and the initial planning factors that will be used under operational conditions. The TALLBOY system illustrates the types of factors that have to be developed, but many of the factors and values (times, ranges, rates of fire, kill probabilities) will differ for other advanced systems.

III. CONFIGURING AN "EXPERIMENTAL FORCE"

Configuring an experimental force is a term used to describe the conceptual formation of an operational unit in the light of a series of considerations. These include the size, organization, tactical concepts, and communication procedures of the unit to be evaluated. This activity is not required when an advanced system is to be incorporated into an existing organization with established structure and procedures.[1] Because this step was required in the two evaluations carried out with this method, it is discussed briefly here.

In the Distributed Area Defense (DAD) concept, a force of small combat units is distributed through a forward defense area in Europe. The force's primary mission is to attrite enemy forces. The operational concept is to try to force attacking enemy units into open areas by using small direct-fire teams in wooded areas or around urban areas to prevent the enemy from using these as cover for his advance. The indirect-fire systems cover the open areas and deliver a high volume of fire against enemy units trying to move along roads or across open country.

To implement the concept, there are two advanced systems: a man-portable, direct-fire, beam-rider weapon, and a mobile indirect-fire, precision-delivery system.

Once the tactical concept and the systems were established, a task-force organization incorporating these systems was developed. Since the area to be defended was one that might be assigned to an armored cavalry squadron, the manning of the task force was assumed to approximate that of an armored cavalry squadron. With this manning as the upper limit and with the notion of many small units operating in the area, a detailed organization was developed, including provision for the necessary support functions. The organization that was developed for the DAD concept is not presented here, since it is not necessarily relevant to other applications of the method. However, such force organizations, tactical concepts, and specific systems are considered "experimental" in the sense that they constituted a force to be evaluated; hence the term "experimental force"—a force whose organization, tactics, and weapon systems differ markedly from those of an existing ground force, and is to be tested by some method.

[1] A reader considering application of the terrain-board/computer-evaluation technique to a system evaluation that does not require the configuration of an "experimental force" may wish to go to the next section.

IV. DEVELOPING A HYPOTHETICAL COMBAT SITUATION

The evaluation of an advanced ground combat system, particularly one that uses precision-guided weapons, requires a detailed representation of a combat area. In the Advanced Employment Concept study, the area chosen for examining the Distributed Area Defense (DAD) concept lay along the border between East and West Germany. To obtain an adequate level of detail, a three-dimensional terrain board was constructed. Figure 3 is a photograph of the terrain board; App. A describes some of its details and its construction.

To develop a hypothetical combat situation, the usual considerations of any detailed computer, or game, exercise are employed. These include:

- The mission(s) of the opposing forces;
- The size of the forces;
- The types of forces;
- The combat organization of the forces;
- Attacker and defender concepts and plans of operations;
- The preattack posture of the opposing forces;
- Any preattack actions and plans of the forces, such as the attacker's artillery fire plans.

All of these factors are established before play begins. Although their specifics are not discussed in this report, several general points can be noted.

Because the exercise is carried out on a terrain board, the positions, movements, and losses of the opposing forces are continuously evident. Before play begins, however, the enemy plans are not known to the friendly forces. To maintain this aspect of "secrecy" in the preattack development of the combat situation in the two evaluations cited earlier, the method allowed one player to do the enemy (RED) preattack planning and another to do the friendly (BLUE) planning.[1]

During the development of the hypothetical combat situation in the period before play begins, RED has some information about BLUE forces. It generally consists of knowledge of the approximate strength of the BLUE forces in the area and fairly detailed knowledge of the types of weapons they have. In the evaluation of advanced systems, RED receives almost complete information about the characteristics and capabilities of the BLUE systems; that is, BLUE is not permitted any "technological surprise." The major limitation on RED is that he does not know the precise locations of the BLUE forces; however, he can surmise likely BLUE positions from the terrain and the characteristics of the BLUE systems. BLUE is also permitted complete intelligence about the characteristics and capabilities of the RED systems, but receives only limited information about the size of the RED attack, and no information on the particular avenues of the RED attack. BLUE

[1] This aspect of the evaluation can be maintained if there are duplicate terrain boards at separate locations, one for RED and one for BLUE, and a play referee or controller intermediates between the two opponents. Use of duplicate boards would permit a fuller exploration of the influence of tactical intelligence on engagement outcome.

Fig. 3—Terrain board

judges what the likely attack routes are, however, and selects his defense positions accordingly.

It is assumed that RED is aware of the characteristics and capabilities of BLUE's systems and has developed any obvious countermeasures. These include tactical countermeasures and technical countermeasures that are within the state of the art.

In developing the combat situation, several limitations were placed on both RED and BLUE forces. Although the evaluation method does not require them, they were introduced because they could drastically change the results of the evaluation. Some of these limitations or "ground rules" were:

- Neither force could use nuclear weapons;
- Neither force could use chemical weapons;
- Weather conditions would remain "typical" of the area; there would be no extremes.

Although the method does not require it, it is useful for obvious reasons to have military personnel with command and operational planning experience participate in developing the combat situations and evaluating the results of the exercise.

V. CONDUCTING THE COMBAT EXERCISE

The primary purpose of board play is to collect data on the performance of advanced systems under a variety of tactical conditions. The exercise must be detailed enough to answer the questions on tactical-technological interactions listed in Table 1. To obtain the necessary data, the play has to allow for both the human decisions involved in employing the systems and the results of these decisions. The method for achieving these objectives appears schematically in Fig. 4.

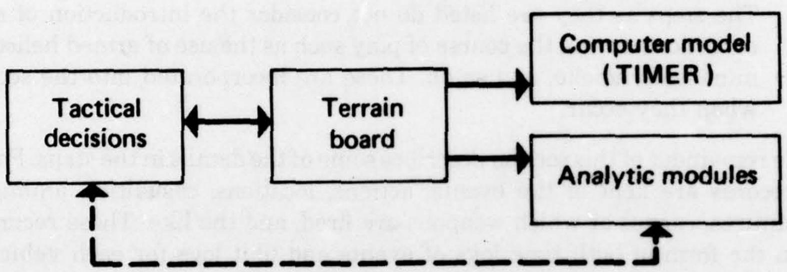


Fig. 4—Basic structure of play method

The terrain board incorporates the geographic features important in positioning and moving the RED and BLUE forces. The computer model—the Terrain Intervisibility and Movement Evaluation Routine (TIMER)—also incorporates the terrain in the form of a digital data base. It is used to determine such factors as the intervisibility between elements of the forces, the length of exposure time, and the opportunities to fire weapons.[1] The analytic modules are small computer programs related to assessing the outcomes of specific engagements. These modules are programmed for a hand-held calculator. The results of the tactical decisions are determined from the combined use of these three devices: the terrain board, the TIMER program, and the analytic modules.

The method permits the detailed inclusion of unit maneuvers and tactical changes in movement in response to the actions of the opposition in order to take advantage of terrain features. This tactical flexibility in varied terrain and under a variety of engagement conditions enables the method to emphasize time-space relationships and maneuver to a far greater extent than a purely computerized model can.[2] This flexibility is important in evaluating precision-delivered muni-

[1] The details of the computer model and examples of its use are covered in greater detail in R-2376-ARPA, one of the two companion reports in this series (see "Preface").

[2] Most computer models are "firepower" models rather than "maneuver" models, and movement of units is often set by specific rules (rates of movement) that are not extensive enough to account for detailed terrain conditions.

tions, whose effectiveness is strongly influenced by the length of time and the range at which targets are exposed.[3]

Because the play of the situation depends strongly on time-space relationships, it sometimes turns into a second-by-second series of activities. It thus consists of an "event-sequence" procedure rather than a continuous time-line procedure. Figure 5 outlines the steps in the overall procedure, but is simplistic for several reasons:

- Actions in a particular step do not occur in a single sequence, but in multiple sequences occurring in different places at the same time.
- The steps involve different periods of time and have to be coordinated when multiple sequences occur simultaneously.
- The steps may involve considerable detail because they are adjusted for the tactical situation existing at the time.
- The steps as they are listed do not consider the introduction of special conditions during the course of play such as the use of armed helicopters, minefields, smoke, and so on. These are incorporated into the sequence when they occur.

The remainder of this section describes some of the details in the steps. For each step, records are kept of the events, actions, locations, casualties, ammunition expenditures, ranges at which weapons are fired, and the like. These records are kept in the form of both time logs of events and unit logs for each vehicle and weapon. In addition, the terrain board used at Rand has a series of overhead camera stations that provide a photograph record of all units in their locations at the end of each sequence. Location and other data are extracted from the photographs.

POSITION UNITS ON TERRAIN BOARD

The BLUE and RED forces are first deployed on the terrain board. As far as possible, each vehicle and weapon is represented by a small-scale model of the vehicle, a marker on a small magnet (the Rand terrain board has a metal plate under the surface), a pin, or other device. Each marker carries identification of its individual number and the type of vehicle or weapon it represents.

A log is maintained for each marker, containing additional information such as the number of troops in the vehicle, the type of equipment, and the number of rounds of ammunition on hand. Depending on the size of the BLUE and RED forces, several hundred vehicles or "pieces" may appear on the board.

INITIATE ARTILLERY FIRE (IF USED)

If the RED force precedes its attack with an artillery barrage, the artillery fire plan is represented by determining the designated aim point for each volley and

[3] It is an oversimplification to describe precision-guided munitions (PGMs) as weapons with which "if you can see the target you can hit it." PGMs generally can hit the target, but the target not only has to be "seen," it has to be seen long enough and within the range of the system in order for a hit to occur.

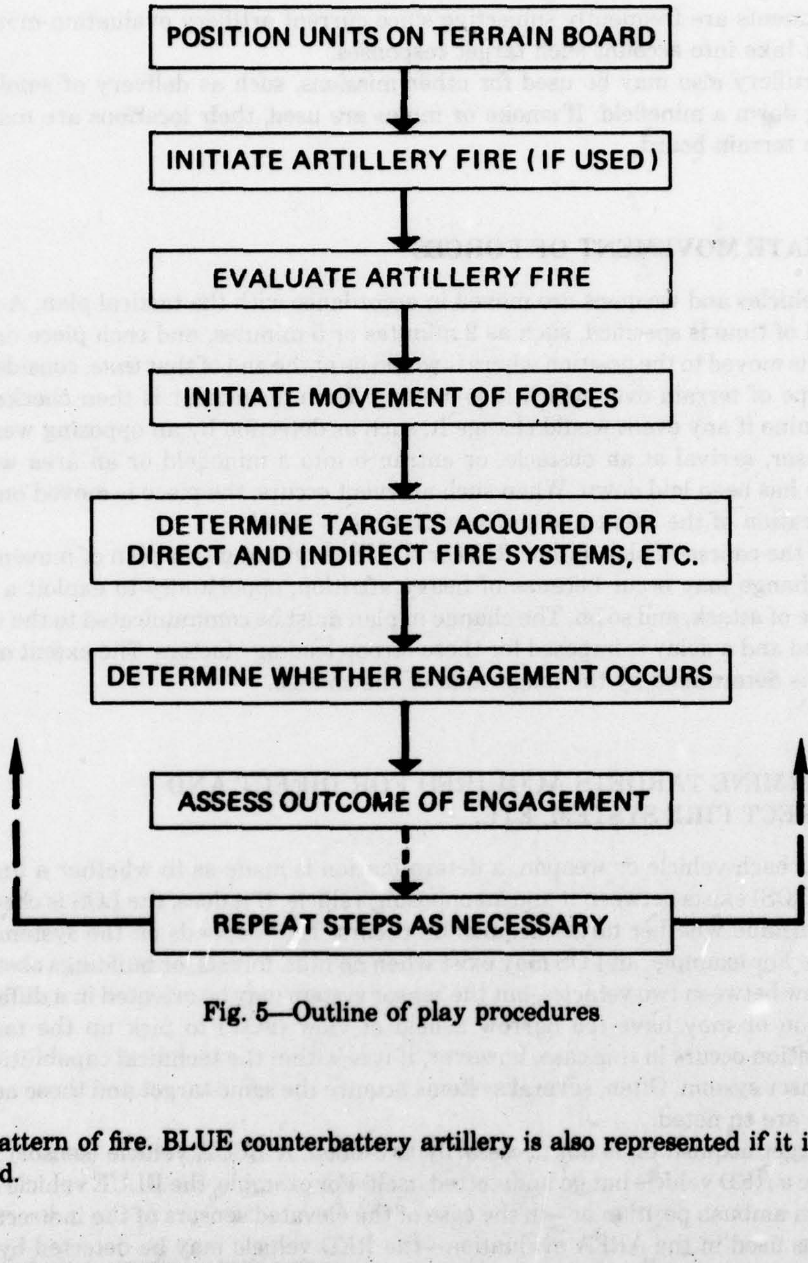


Fig. 5—Outline of play procedures

the pattern of fire. BLUE counterbattery artillery is also represented if it is employed.

EVALUATE ARTILLERY FIRE

The aim point location of each artillery volley is checked to determine if there is a target in the area. If a target is present, the results of the artillery fire are determined based on the type of round, proximity to target, and type of target. In general, standard procedures for evaluating artillery effectiveness are used, such as those of the Joint Munitions Effectiveness Manual (JMEM). On some occasions these results have to be adjusted because the target moves out of the immediate area, or because troops go from a standing position to a prone position. These

adjustments are frequently subjective since current artillery evaluation methods do not take into account such target responses.

Artillery also may be used for other missions, such as delivery of smoke or laying down a minefield. If smoke or mines are used, their locations are marked on the terrain board.

INITIATE MOVEMENT OF FORCES

Vehicles and weapons are moved in accordance with the tactical plan. A fixed period of time is specified, such as 2 minutes or 5 minutes, and each piece on the board is moved to the position where it would be at the end of that time, considering the type of terrain over which it is moving. Each movement is then checked to determine if any event would change it, such as detection by an opposing weapon or sensor, arrival at an obstacle, or entrance into a minefield or an area where smoke has been laid down. When such an event occurs, the piece is moved only to the location of the event and the specific time is noted.

In the course of play, either RED or BLUE may change his plan of movement. This change may occur because of heavy attrition, opportunity to exploit a new avenue of attack, and so on. The change in plan must be communicated to the units affected and a delay is imposed for these "troop leading" factors. The extent of the delay is determined by the magnitude of the change.

DETERMINE TARGETS ACQUIRED FOR DIRECT AND INDIRECT FIRE SYSTEM, ETC.

For each vehicle or weapon, a determination is made as to whether a line-of-sight (LOS) exists between it and an opposing vehicle. If it does, the LOS is checked to determine whether target acquisition occurs. That depends on the systems involved. For example, an LOS may exist when no hills, forests, or buildings obstruct the view between two vehicles, but the sensor system may be oriented in a different direction or may have too narrow a field of view (FOV) to pick up the target. Acquisition occurs in this case, however, if it is within the technical capabilities of the sensor system. Often, several systems acquire the same target and those acquisitions are so noted.

Target acquisition is not necessarily two-sided. A BLUE vehicle (sensor) may acquire a RED vehicle but go undetected itself. For example, the BLUE vehicle may be in an ambush position or—in the case of the elevated sensors of the indirect-fire systems used in the ARPA evaluation—the RED vehicle may be detected by the IR sensor without knowing it. When a vehicle enters a minefield, the vehicle is "acquired" when it detonates the first mine.

DETERMINE WHETHER ENGAGEMENT OCCURS

After all the various acquisitions have occurred, the determination of whether an engagement occurs is made. Several factors affect this determination; for example:

- The target may be out of range of the weapon system.
- The target may be within range, but not fired on until more targets are acquired.
- The target may be within range, but firing at long range may result in a low probability of hit. (This situation is less likely for precision-guided weapons.)
- The target may be within range, but can move behind an obstacle before a precision-guided munition could arrive.
- The target may be in the sector of responsibility of another weapon system, and standard operating procedure (SOP) may require withholding fire.
- The target may be within range of several systems, which may withhold fire while only one engages the target.

These and other factors depend on the tactical situation and the combat systems being evaluated. Some of the factors will clearly indicate the types of tactical-technological interactions that can occur in the course of play, as well as the utility of the manual play on the terrain board for evaluating advanced systems. For example, coordination is important between two advanced systems that have acquired the same target and that employ "expensive" precision-guided munitions; the play indicates where tactical decisions, that otherwise might result in overkill and wastage of munitions, relate to the technological characteristics of the advanced weapon systems.

ASSESS OUTCOME OF ENGAGEMENT

The assessment of outcomes usually follows standard procedures based on the hit and kill probabilities of the weapon systems. As an aid to assessment, a series of "analytic modules," or programs, for a hand-held calculator were developed for the advanced weapon systems being examined. Although these programs are applicable only to these specific systems, and therefore are not part of the general methodology, one is presented in App. B as an illustration.

Each engagement taking place during the time period established earlier is assessed until all actions are accounted for. The status of all forces is then changed to account for losses, damage, ammunition expenditures, and so on. The markers for destroyed vehicles or systems are left on the board because they affect the movement of following vehicles. RED and BLUE then continue their tactical operations by repeating appropriate portions of the sequence: artillery fire, movement, target acquisition, and engagement. As play progresses, a variety of tactical situations develop and are assessed. In each of the two ARPA exercises, for example, about 150 to 200 engagements occurred during the 2 to 3 hours of combat. By the end of the play (usually marked by the RED forces reaching their established objectives, or stopping because of attrition), a large amount of quantitative data on the advanced systems has been collected as well as a large number of qualitative assessments related to the tactical employment of the systems.

VI. ANALYZING DATA FROM THE COMBAT SITUATION

The data collected include the unit and time logs of events, the overhead photographs, and the computer data, plus observations made during the course of play. This section describes some of the types of analyses that can be performed with these data, using TALLBOY and the "guided mortar" system for illustration.

The time log gives the events of the play in the format indicated in Table 2, which is annotated to illustrate the entries.

Table 2

SAMPLE OF TIME LOG DATA

Item	Entry	Annotation
Time	00200	In seconds from start of combat
Unit	B46	Identification number of BLUE unit
Coord	958 865	Location of unit in UTM coordinates
Vehicles	4	Number of vehicles in unit
Status	PT	Posture: In Position in town
Activity	A	Acquires target
Unit	R133	Identification number of RED unit acquired
Range	2300	Range to acquired unit
Type	V	Type of acquisition;Visual contact
Time C	15	Time in contact, in seconds
Vehicles	3	Number of vehicles contacted
Velocity	15	Speed of vehicles, in kph
Ammo	16	Number of rounds in BLUE unit
(A later log entry, at time 00220, would carry additional entries)		
Activity	F	BLUE unit fires
Range	2280	Range at time of firing
Rounds	2	Number of rounds fired
Results	1	One kill on RED unit

The logs reveal which vehicles or weapons were used in the play, how many times they were engaged, their posture at the time of engagement, the ranges of acquisition and firing, the kills obtained, and other data. As an illustration, in the guided-mortar evaluation, Table 3 lists the total RED losses in two lead regiments during about 2½ hours of combat.

Table 3

RED LOSSES

Initial force	390 vehicles/weapons
Losses:[a]	
Number	300 vehicles/weapons
Percent	77%
Location:	
Woods	20% of losses
Open	76% of losses
Urban area	4% of losses
Exchange ratio: R/B[b]	8:1

[a]Cause of loss not presented here.

[b]Ratio between RED vehicle and weapon losses and those of BLUE.

The log data also enable other results to be extracted. For example, the guided mortar was used in conjunction with an advanced man-portable direct-fire system. Of the total RED losses in both the lead and following regiments of the attack, 183 were the result of the direct-fire system, whose maximum range was about five kilometers. The play produced the kill-vs.-range data in Fig. 6, which illustrates the interaction between tactics and technology. The direct-fire system produced over 90 percent of its kills at less than one-half its design rang and about 70 percent of its kills at ranges under 1000 meters.

These results have immediate technological implications for the system. The heavy weighting of kills toward the shorter ranges is largely due to the tactical concept employed: The direct-fire weapons were positioned to interdict RED movement through covered areas—forest roads, towns, and the like. Being direct-fire weapons, they would probably be employed from protected positions in combat. This immediately suggests the type of "sight" mechanism that the weapon should have. For short ranges, a light, boresight mechanism would be more appropriate than a heavier, magnification sight that could add additional cost to the weapon. Or, as a design option, the weapon could incorporate interchangeable sights for different tactical situations.

Log data can be supplemented with data derived from the computer program (TIMER), which was used for calculating intervisibility. In the guided-mortar evaluation, the RED attack came on six different avenues represented on the terrain board. The TIMER program calculated the location, number, and length of all stretches of these six attack routes that were visible—that is, in which an LOS existed between BLUE's elevated sensor and the routes. As expected, the higher the sensor the greater the number and length of the visible stretches, and the more opportunities to use the guided mortar. To quantify this relationship, a metric called a "firing opportunity" was developed. It took two factors into account:

1. The length of time a RED vehicle is exposed on a visible stretch, which depends on its speed, and
2. The ability to deliver ordnance (the guided mortar round in this case), which depends on the length of time it takes for the system to respond

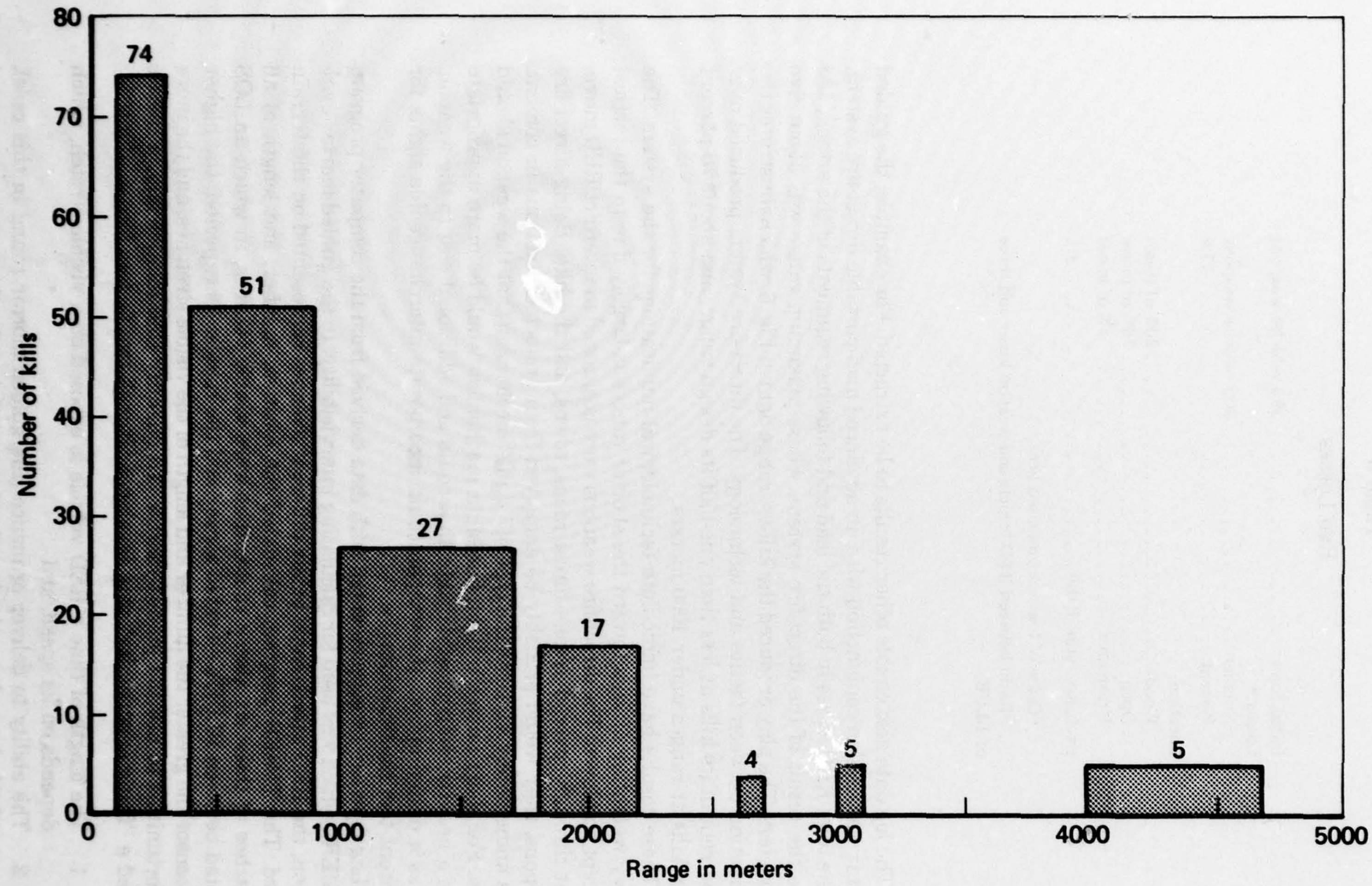


Fig. 6—Direct-fire system kills versus range (total kills = 183)

once a target is in view. The system's ability to respond is called its "reaction time," which is defined to encompass LOS contact, orienting, launching, and time-of-flight (TOF) of the round.

The number of firing opportunities can be determined from the intervisibility data on the number of visible stretches and their lengths. For example, if a target is moving at 30 kilometers per hour (500 meters per minute), and the system reaction time is two minutes, the system requires a stretch of 1000 meters between LOS contact and impact of round. Each 1000 meters of visible stretch thus provides, theoretically, one firing opportunity against targets moving at this speed. By processing the data on visible stretches, the computer can calculate the number of firing opportunities for other conditions. For example, it can calculate the effect of increasing the height of the sensor platform on the number of firing opportunities. Figure 7 depicts the relationship between platform height and firing opportunities for the following conditions:

- The visible stretches forward (180°) of the initial positions of the entire force of the guided mortar sensors;
- A weapon range of 5000 meters;
- RED vehicle velocity of 30 kph; and
- A reaction time of 120 seconds for the guided mortars.

Figure 7 provides another illustration of the usefulness of the method: It indicates the gain in firing opportunities as the height of the sensor platform is increased, an advantage that increases little above 100 meters. Such data are useful for determining the trade-off between the technological (with associated cost) implications of sensor platform height and its tactical value.

This example also illustrates a qualitative aspect of the evaluation. In the guided mortar system, the sensor platform was elevated by a tethered rotor that took some time to deploy from the vehicle. The higher the platform was raised, the longer it took to retract. On several occasions during game play, a sensor vehicle was almost lost because it came within range of an enemy tank while still retracting its platform before moving to a new position. This suggested the possibility of adding some form of antitank protection to the sensor vehicle, a technological and organizational design requirement related to the tactical employment of the system.

The firing opportunity metric also permitted assessment of the effect of changing the reaction time of the guided mortar system. Figure 8 graphs this relationship and illustrates the value of shortening reaction time, which perhaps could be done by designing automated decisionmaking aids for the crew. This would be much more effective than increasing platform height.

The TALLBOY analysis also illustrated the usefulness of the method. In the TALLBOY system, the sensor is mounted on an extendable pole, with a maximum height of about 30 meters. For that height, Fig. 9 shows the relationship among reaction times, firing opportunities, and range of the TALLBOY missiles.

This figure also indicates the advantages to be gained by shortening reaction times or increasing the range of the missile, or both.[1]

[1] Although Fig. 9 indicates far more firing opportunities for TALLBOY than for the guided mortar, the two systems should not be compared on this basis because: (1) There were six times as many

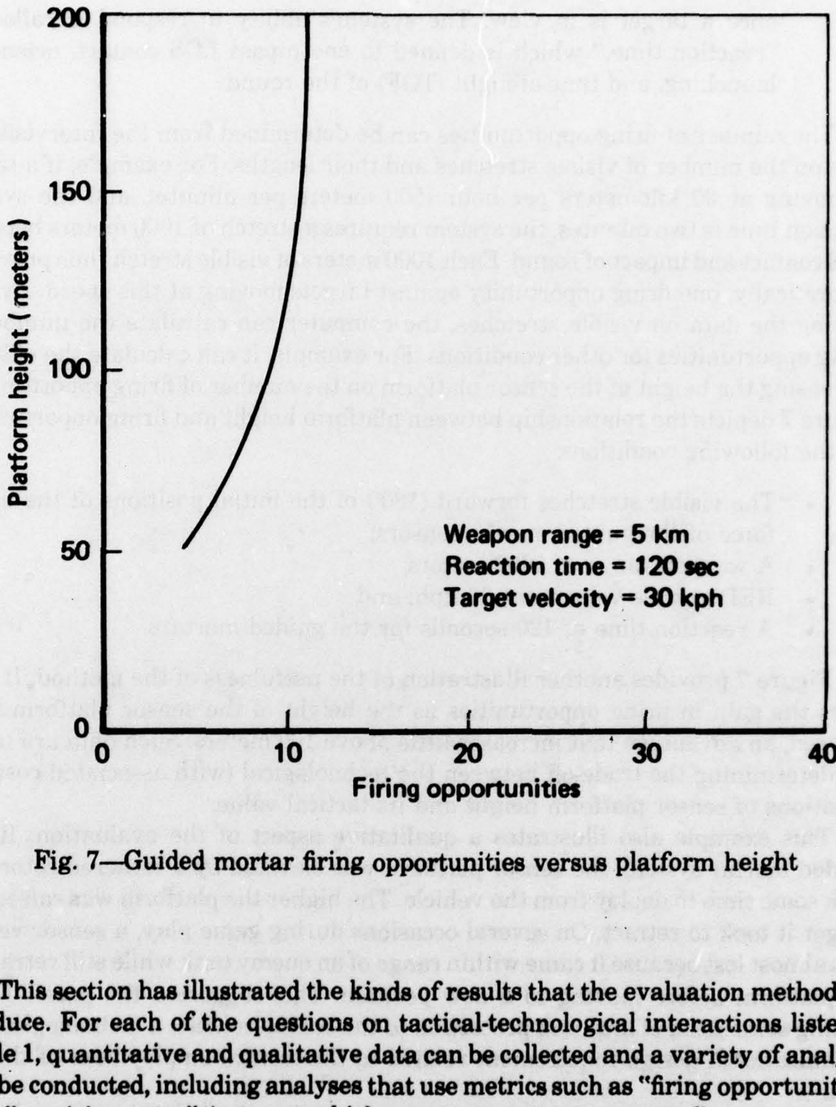


Fig. 7—Guided mortar firing opportunities versus platform height

This section has illustrated the kinds of results that the evaluation method can produce. For each of the questions on tactical-technological interactions listed in Table 1, quantitative and qualitative data can be collected and a variety of analyses can be conducted, including analyses that use metrics such as "firing opportunities" and "servicing rates" (rates at which enemy targets are engaged).

Detailed play involving an experimental force, with tactical freedom of action by both sides, can provide a "synthetic history" of combat under controlled conditions. By judicious use of the evaluation procedure, a large amount of data covering many combat conditions can be collected and analyzed, revealing the performance of advanced systems in a dynamic environment.

TALLBOY vehicles in the TALLBOY evaluation as there were sensor vehicles in the guided-mortar evaluation; and (2) the target velocity in the TALLBOY data was 12 kph vs. 30 kph in the guided mortar data.

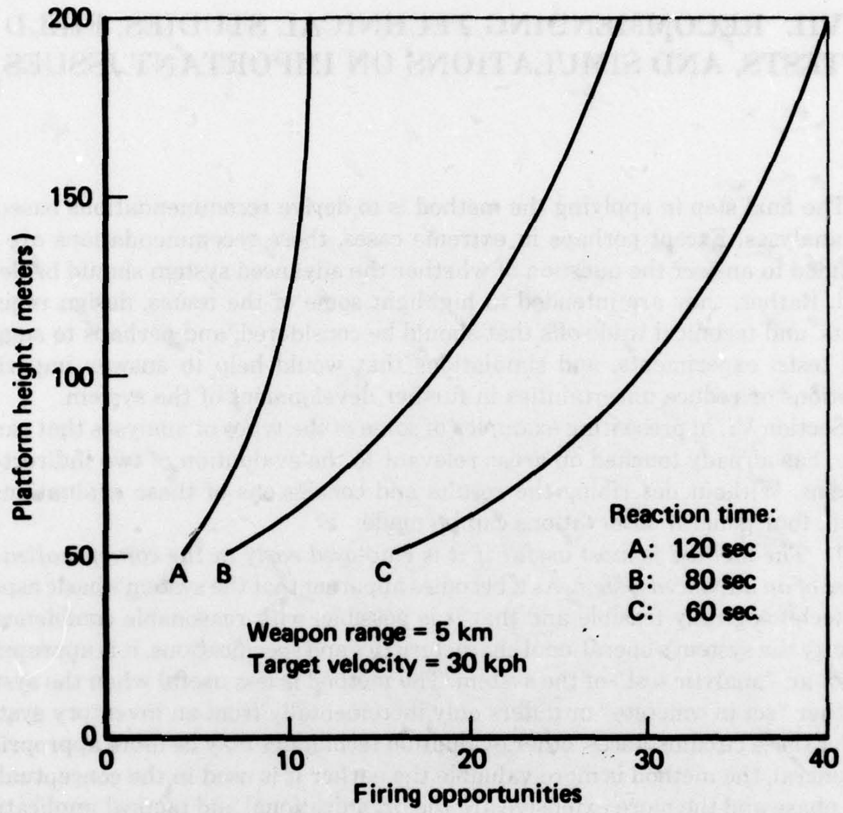


Fig. 8—Guided-mortar firing opportunities for various reaction times

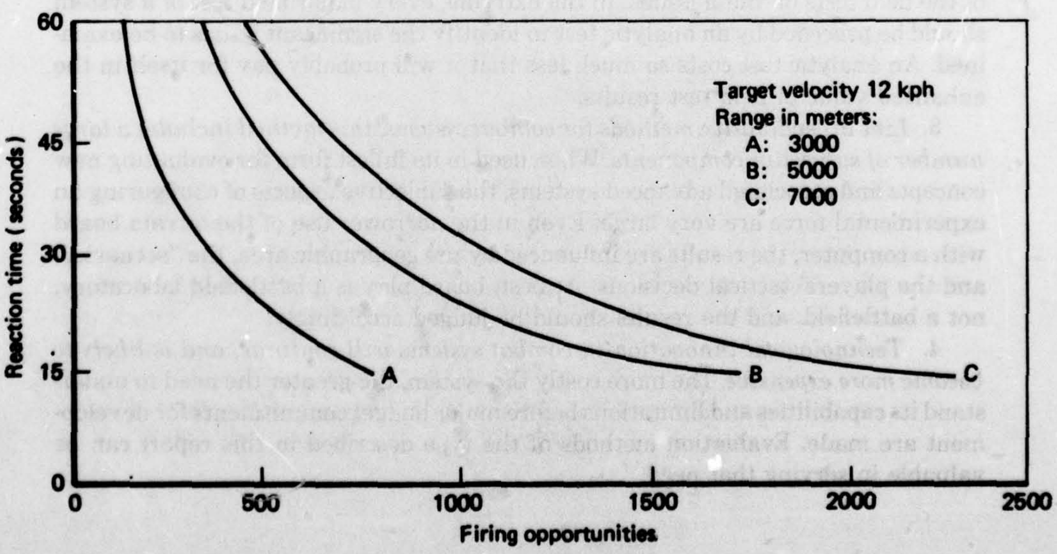


Fig. 9—Effect of TALLBOY reaction time on firing opportunities, for a sensor height of 30 meters

VII. RECOMMENDING TECHNICAL STUDIES, FIELD TESTS, AND SIMULATIONS ON IMPORTANT ISSUES

The final step in applying the method is to derive recommendations based on the analyses. Except perhaps in extreme cases, these recommendations are not intended to answer the question of whether the advanced system should be developed. Rather, they are intended to highlight some of the issues, design requirements, and technical trade-offs that should be considered, and perhaps to suggest field tests, experiments, and simulations that would help to answer important questions or reduce uncertainties in further development of the system.

Section VI, in presenting examples of some of the types of analyses that can be done, has already touched on areas relevant to the evaluation of two indirect-fire systems. Without describing the results and conclusions of these evaluations in detail, four general observations can be made:

1. *The method is most useful if it is employed early in the conceptualization phase of an advanced system.* As it becomes apparent that the system's basic aspects are technologically feasible and that it is possible, with reasonable confidence, to identify the system's operational characteristics and specifications, it is appropriate to run an "analytic test" of the system. The method is less useful when the system is either "set in concrete" or differs only incrementally from an inventory system. Under these circumstances, other evaluation techniques may be more appropriate. In general, the method is more valuable the earlier it is used in the conceptualization phase and the more extensive are the organizational and tactical implications of the advanced system.

2. *Even for some systems that are in development, the method can be useful in defining the significant aspects, particularly for field tests.* To the extent that the method can identify critical performance or design questions, it can direct the focus of the field tests on these issues. In the extreme, every major field test of a system should be preceded by an analytic test to identify the significant issues to be examined. An analytic test costs so much less that it will probably pay for itself in the enhanced value of field test results.

3. *Like all evaluative methods for combat systems, this method includes a large number of subjective components.* When used in its fullest form for evaluating new concepts and associated advanced systems, the subjective aspects of configuring an experimental force are very large. Even in the narrower use of the terrain board with a computer, the results are influenced by the geographic area, the "scenario," and the players' tactical decisions. At best, board play is a battlefield laboratory, not a battlefield, and the results should be judged accordingly.

4. *Technological innovation in combat systems will continue, and is likely to become more expensive.* The more costly the system, the greater the need to understand its capabilities and limitations before major budget commitments for development are made. Evaluation methods of the type described in this report can be valuable in serving that need.

Appendix A

TERRAIN BOARD CONSTRUCTION

This appendix provides some background information on constructing the type of terrain board shown in Fig. 3 above.

CHOICE OF THE AREA TO BE REPRESENTED

The terrain board was first used for evaluating a Distributed Area Defense concept in a forward area, a portion of the border between East and West Germany. This area was chosen because of its mix of hills, open areas, forest cover, road nets, and towns. An area about 20 kilometers wide by 25 kilometers deep was chosen to allow scope for the play not only of individual firefights, but of unit redeployment, battlefield area logistics, and communications in a battle that might take place over several hours. The scale of the terrain board was partly dictated by the practical need for a player to be able to reach an arm to the middle of the board. At a scale of 1:10,000, one kilometer is 10 centimeters; a board representing an area 20 by 25 kilometers thus measures about 2 meters by 2.5 meters.

CHOICE OF MATERIALS

A variety of materials may be used for terrain board construction. Styrofoam is one common choice. The Rand board uses 3/16-inch birch plywood, to which 20-mil steel sheet is cemented. This choice was made (1) to achieve ruggedness, (2) to obtain a vertical exaggeration of 2.5 to 1 at a contour interval of 20 meters, highlighting terrain characteristics without affecting line-of-sight estimates, and (3) to permit the use of unit symbols mounted on small magnets that reduced the chance of inadvertent displacements when working on the board.

CONSTRUCTION PROCEDURE

1. Piece together sections of base maps at a scale of 1:50,000 (AMS M745 series), covering the desired area. From a full-size negative, make a five-fold enlargement, and then three prints. Two prints are required for the construction, and one is held in reserve to be used in case of errors.
2. Cut the prints into 16 sections, each about 20 by 24 inches, and cement them to the steel-plywood laminate using spray photomount adhesive. This section size eases contour cutting with a bandsaw, simplifies final assembly, and makes the heavy completed board mobile.
3. With a red pencil, go over the contour lines on one set of sections at intervals of 40 meters. Do the same on a second set of sections, but offset

the lines by 20 meters from the contour lines of the first set, to provide for overlap.

4. Cut along all marked contours on both sets with a bandsaw, yielding strips or ribbons, irregular in size and width. These strips are closed annuli for mountains that fall completely within a section. Otherwise they are open.
5. Starting with the section that has the lowest elevation for the entire area, build up "rice paddy" terraces by alternating and overlapping strips from the two sets of sections, gluing them together. A base of ½-inch plywood is used.
6. As layers are built up, some cantilevering occurs. When necessary, support the evolving structure with 5/16-inch birch dowels, cut to length, and check periodically to avoid accumulating altitude errors.
7. If the prints are black and white, hand-color foliage and hydrographic features green and blue, respectively.
8. The final sections are placed butting together on four work tables or other framework, at a comfortable working height.
9. Ceiling stations to hold a 35 mm camera are installed to obtain overlapping coverage of the board. Photographs provide a hard-copy record of the locations of all opposing units at intervals during an evaluation.
10. The sides of those sections forming the perimeter of the board can be dressed with vertical ⅛-inch plywood cutouts, if desired.

The materials for the Rand terrain board cost about $700, including black-and-white photographic enlargements of the basic maps. Construction took approximately 650 man-hours.

Appendix B

AN ANALYTIC MODULE

This appendix presents one example of assessing an engagement outcome using a programmable hand calculator (the Hewlett-Packard HP-67).

BACKGROUND

A typical combat situation in the evaluation exercise generates several hundred firefights. Some of them are one-sided, with a concealed defensive unit firing against a target element such as an enemy armored unit in the open. Assessment could be made by expected value: "Kills" equal rounds fired times single-shot kill probability. This procedure is inappropriate, however, for three reasons: (1) It could "kill" more targets than are present, (2) it does not reflect a fire-allocation process, and (3) it does not allow for statistical variations in the outcome. As an example of the third point, a "lucky" enemy unit may survive several engagements and overrun a key defense position in spite of heavy fire.

It is more realistic to construct a probabilistic Monte Carlo model from which sampling by random numbers will produce an assessment. This approach was used for many of the analytic modules that were developed for the evaluation method described here.

EXAMPLE FOR THE CONCEPTUAL MORTAR ROUND

In evaluating the precision mortar round, the round was assumed to possess a heat-seeking sensor head and a means for terminal maneuver, so that it could home on a hot target. Because the terminal angle of the trajectory is steep, the engine compartment of any enemy tank is an attractive heat source.

The sensor design should gate out other intense heat sources such as a burning or exploding vehicle (K-kills). However, follow-on rounds may hit targets immobilized by previous fire (M-kills). Such overkill, a common battlefield event, further degrades the actual combat kill probability achieved.

THE MODEL

Suppose that there are A moving targets at the start of the engagement. The firing opportunity interval (time) is such that N rounds can be fired or, otherwise, the ready-rack load available is N rounds.

Let r be the probability of an M-kill, immobilizing the target. Let s be the probability of a K-kill, with the target exploded or set afire. The rounds are ripple-fired. At the time the nth round arrives ($n \leq N$), there are j vehicles still moving and k vehicles either still moving or immobilized by previous fire ($j \leq k \leq A$). Hence,

A − k vehicles have had a K-kill and are no longer targets, and k − j targets have had an M-kill.

After the nth round impacts in the target area, there are four possible state changes.

(1) (j,k) → (j,k). That is, the nth round did not get a K-kill (k does not change) nor did it get an M-kill on a moving target (j does not change). It is irrelevant if the round gets an M-kill on one of the k − j targets already immobilized. The probability of these events is

$$P_1 = 1 - s - rj/k,$$

because j/k is the chance the round picked a moving target.

(2) (j,k) → (j − 1, k). This means an M-kill on a moving target; j reduces by 1, and k does not change.

$$P_2 = rj/k.$$

(3) (j,k) → (j − 1, k − 1). There is a K-kill of a moving target; both j and k reduce by 1.

$$P_3 = sj/k.$$

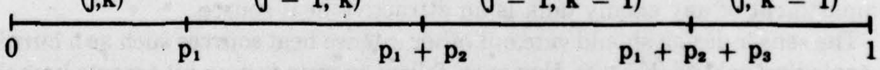
(4) (j,k) → (j, k − 1). There is a K-kill of an immobilized target.

$$P_4 = s(k - j)/k.$$

The sum of these four probabilities is 1.

THE PROGRAM

The HP-67 program[1] generates a (pseudo) random number in the interval (0, 1) for each round fired. The assessment depends on the interval in which the random number falls.



The program accumulates the results for N rounds, although fire will stop if all targets have had a K-kill.

As an example, suppose r = 0.2, s = 0.3, A = 5, N = 6. Line 1 of the tabulation below shows an assessment that might be logged for the *first* time this engagement occurred. For a further engagement occurring later in the exercise, still with A = 5 and N = 6, the assessment could be one of the other lines, depending on the position in the random number stream being generated during the exercise. Assessments for ten engagements might be the following:

[1] The program is given in *Hand Calculator Programs for Staff Officers*, E. W. Paxson, The Rand Corporation, R-2280-RC, April 1978.

	M-kills	K-kills	Rounds Left
1	1	2	0
2	2	3	0
3	0	2	0
4	0	4	0
5	1	3	0
6	0	2	0
7	0	2	0
8	1	1	0
9	2	0	0
10	0	2	0

For each engagement in the play that meets the tactical conditions, the appropriate values of A and N are input, and the analytic module produces the engagement outcome.